A SUMMARY OF CERTAIN ASPECTS OF THE SCARAB PROBLEM, AND A CONTRIBUTION TO A BIBLIOGRAPHY OF THE FAMILY SCARABAEIDAE.

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During the last two years the writer has carried out certain investigations on the larvae of Australian species of the family Scarabaeidae. It is thought that a summary of certain aspects of the problem, together with a bibliography of the literature consulted during the work, may be of future use. In an appendix two bibliographical lists have been included; the first deals with work done overseas, and is subdivided into morphological, physiological, ecological and miscellaneous sections, together with some papers on breeding and rearing technique; the second, dealing with Australian economic species, is listed under the host plants. The first list includes only relatively few publications out of the mass of literature dealing with this group, and is published in the hope that it may save part, at least, of the preliminary reading necessary in starting any problem. The second list is not entirely complete, but does cover most of the species known to be injurious.

A Summary of Certain Aspects of Conditions Affecting Scarabaeidae of Economic Importance.

The eggs are laid some inches below the soil surface, in spring and early summer, being usually deposited in clusters in cavities made by the female. The larvae work their way upwards after hatching, and feed at varying depths below the soil surface. Feeding generally takes place at night: the larvae may approach the surface sufficiently close to disturb it. There are three instars: the total life-cycle ranges from three or four months to three years (in some North American Scarabaeidae). Feeding takes place all through the summer. During the winter the larvae are found at greater depths, enclosed in small cells moulded by pressure of the body on the surrounding soil particles. This cell may also be formed at any time when the larva is not feeding. The depth to which the larvae descend depends on the climate, the size of the larva and the ease of penetration.

The following spring, the larvae work their way up again and feed on the young roots. In young plants the roots are cut off right to the stem, all new rootlets devoured, and the plant may even be pulled entirely under the surface as the larva feeds. It is at this time that the damage is most apparent, becoming manifest as areas of stunted growth and dead plants. Plants are always more affected where conditions are adverse to vigorous growth, but these conditions usually also render the soil habitat more unfavourable for larval development. Where growth is strong, the plants may outgrow the grub attack; this is an important factor in limiting larval damage. In those species with a two-year life-cycle the damage is greater and extends over a more prolonged period, the larvae passing two winters in a dormant state. The damage even with the heaviest grub population is not very apparent until the final instar.

When the larva is fully grown it again burrows downwards. Ritcher (1939) states that the depth of pupation varies with the species and the type of soil; he concludes that soil factors may affect the pupation levels, but do not alter the relative positions of the various species, and also that differences in latitude seem to have little effect on the depth at which a given species pupates. The larva enters the prepupal state when it sheds the rectal contents, which are used as a plaster in the formation of the ovoid pupal cell. This plaster ensures a fairly firm and impermeable structure. The prepupa has a creamy-white appearance, and just prior to pupation is incapable of any movement but a restricted jerking of the abdomen. The pupa is of the exarate type. The adult requires several days after emergence before it hardens and assumes the proper colouration: until then it does not leave the pupal cell. The adults usually first emerge

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in early spring or summer (notable exceptions are *Metanastes vulgivagus* and *Heteronychus sanctae-helenae*, which emerge towards the end of summer and hibernate in the adult form), and may have a life-time of two to three months, during which period they lay numerous egg-batches.

The beetles of this family are both diurnal and nocturnal; during their quiescent periods they congregate under rubbish on the ground, or beneath the soil surface. During feeding or copulation periods they appear in swarms. In the main, they attack foliage, many confining themselves to native vegetation, but some attack vines and orchard trees, doing considerable damage. *Anodontonyx noxius* (*A. tetricus*) is found in the field in the afternoon; the adults have never been observed to feed above ground, emerging apparently to copulate (McCarthy, 1928). On the other hand, *Anoplognathus* species are to be seen swarming over Eucalypts during the day and completely stripping the young trees: copulation in these species also takes place above ground. *Sericesthis pruinosa* is a crepuscular species (Froggatt, 1919); the majority of the Dynastinae are nocturnal.

Oviposition preferences and mating habits vary. The females of *Anodontonyx noxius* show a decided preference for freshly turned soil when they return after copulation. Soil worked some weeks prior to the appearance of the beetles, or land free from natural growth is more attractive than stubble or grassed land (McCarthy, 1928). *Heteronychus sanctae-helenae* lays its eggs chiefly in low-lying paspalum land (*Agric. Gaz. N.S.W.*, 1936), *Aphodius tasmaniae* is attracted particularly to areas rich in sheep dung (Swan, 1934). *Lepidiota caudata* prefers buildings, trees, charred stumps, etc., on which to mate, and mating females fall to the ground, burrow in and oviposit. Eggs are not normally laid in land which is fallowed at the time of flight (Smith, 1936). Mating habits and oviposition preferences are of importance because they enable prediction of the degree of larval concentration in various areas.

The spread of any species of scarab is erratic, depending mainly upon the movements of the adults. These, although capable of sustained flight, do not often use this capacity, and there is no marked migration. The larval damage is usually scattered, present in one part of a district and absent from others; in one paddock, while surrounding ones are barely damaged. Larvae move freely in a vertical direction in sympathy with changes in moisture levels during the year; their outward horizontal movement may be limited, although opinion is divided upon this point. Smith (1936) states that the areas of damaged pasture gradually extend owing to the lateral migration of the larvae, until each area may cover an acre or more, and several may merge before larval development is completed. Illingworth and Dodd (1921) on the other hand state that normally there is little lateral movement of the grubs in the soil. The apparent advance of the larvae across the fields is marked by the yellowing of the cane-tops. This is explained by relative infestation: the parts of the field nearest the feeding and mating trees are more heavily infested. *Aphodius tasmaniae* larvae do migrate, digging new burrows as they move outwards (Swan, 1934). Experiments on larval migration have been carried out in Germany (Schwerdtfeger, 1939). The larvae of *Melolontha melolontha*, during the vegetation period, move mainly horizontally from root to root. The rate at which the larvae migrated in summer was dependent on temperature, the size of the larvae, and the structure of the soil: it is calculated that in nature a larva covers an average total distance of about five to six and a half feet, with a maximum of about ten to fifteen feet. The spread of infestation by larval migration is therefore negligible in forests, but is of greater importance in gardens. According to this author, the vertical migration is comparatively slight, the average movement being between approximately five and nine inches in summer, and fourteen and twenty-three inches in winter. Larvae of *Popillia japonica* (Hawley, 1934 and 1935) under greenhouse conditions have moved horizontal distances as great as seven feet, which is as far as the bins used in the tests would permit. There was considerable individual variation in the distances travelled, but the tendency to move about is much more evident in fallow ground than in grass sod. Under natural conditions the distance travelled is not nearly as great, since the larvae change the direction of their movement at frequent intervals.

The larval habits of the various species are in general similar. *Aphodius tasmaniae*, as already mentioned, differs in the construction of vertical tunnels in the soil. The larvae have fairly decided food preferences, according to Hayes (1929), who collected extensively through North America.

It is generally considered that scarab larvae feed both on living roots and on humus. It does not seem definitely known whether the larvae feed on living roots in preference to the humus in the soil, or whether humus is their primary food, roots being attacked only when there is a deficiency of organic matter in the soil. It is stated that *Heteronychus sanctae-helenae* larvae feed chiefly on decaying organic matter (*Agric. Gaz. N.S.W.*, 1936) and also that larvae of *Anodontonyx noxius* (*A. tetricus*) live in the early stages on roots of weeds and grasses as well as on humus, although they can subsist entirely on the latter (McCarthy, 1928). Illingworth and Dodd (1921) stated that larvae of sugar-cane beetles normally depend upon humus for their food, adducing various observed facts in support of their statement. The only experimental rearing of larvae was done by Fox and Ludwig in America (1937); they found that it was possible to rear larvae of the Japanese beetle from egg to adult on decayed vegetable matter alone, although in such instances development was somewhat retarded as compared with that of larvae also supplied with other food, such as grains of wheat. They later (1938) published the results of a lengthy series of experiments on the same species (*Popillia japonica*) in an attempt to find the medium which would be most satisfactory for rearing purposes: from these experiments some interesting conclusions have been reached. The media used were various kinds of decayed plant matter, soil, living and dead wheat, and yeast. It was found that the only medium which was satisfactory when used alone was *Andropogon* "mould", and it was inferred that the same may be true for "moulds" derived from Gramineae (grasses) in general, and especially from the more succulent forms such as the common pasture and lawn grasses. If this is so, it seems that living roots are not essential for larval growth under natural conditions. Soil plus *Andropogon* "mould" gave the maximum survival for the entire larval period. The improvement in survival attending the addition of wheat to the various media appears to bear an inverse relation to the taxonomic affinities of the plant furnishing the "mould" to the grasses. It appears from this that larvae under lawns and pastures would be able to survive without attacking the plant roots, but for the inadequate supply of disintegrated plant matter where the population is dense. Smith (1936), in dealing with *Lepidiota caudata* on the Atherton Tableland, states that although the humus content of the soil in grub-infested districts is generally good, the activity of the pest shows no parallel with the several available humus determinations, deducing therefore that the humus content can hardly be a controlling factor in larval distribution.

The larvae have quite a definite effect upon the soil and vegetation, apart from actual attack, the magnitude of the effect being directly proportional to the numbers of the larvae. There is the mechanical effect of disturbance by continual movement of the larvae through the soil (the soil may become very friable and dry through freer circulation of air, thus greatly affecting shallow root systems, part of which will have already been destroyed), and the chemical and physical effect of ingestion of quantities of soil from which the humus is removed in transit. Where the larval population is high, the soil may assume "pellet" characteristics. Where *Aphodius* larvae occur in numbers so much soil may be thrown out of the burrows that the soil surface is covered by a loose mulch nearly one inch in depth. The regeneration of pasture already destroyed by the feeding activities of the grubs may be prevented, resulting in bare patches. Smith (1936) showed that the white grub population in pastures induced alterations in soil capillarity, indicating a marked disturbance in the moisture-holding capacity of the soil.

The prolonged subterranean existence of a scarab renders the conditions prevailing in its soil habitat of extreme importance. The egg, larval and pupal stages are all spent in the soil: these comprise the major part of the life-history, rated as high as 98% of the total life-cycle. Also adults have in most species less of a terrestrial than a subterranean existence. For instance, the introduced species *Heteronychus sanctae-helenae* normally spends several months underground during winter, while conditions may force imagines of other species to remain in their pupal cells for more or less protracted periods. This occurs when the soil is dry and packed hard so that it is impossible for them to force their way out. In such a case the adult mortality is high. When the earth becomes sufficiently moist the emerging swarms will be formed of a mixture of recently transformed and older adults. The incidence and duration of the flight period and the intensity of the flight are thus subject to marked fluctuations. Smith (1936) states that in Queensland spring rainfall is directly correlated with the seasonal importance of the pest species *Lepidiota caudata*, since beetle emergence depends entirely upon a prior soaking of the soil. It is interesting to notice, as he points out, that seasons which the farmer would consider favourable for dairying, i.e., seasons which are characterized by good spring rains, are equally favourable to the pest, liberating swarms of adults. A susceptible belt is much better served by a rainfall which limits the beetle emergence.

Eggs cannot withstand desiccation. For *Melolontha melolontha* L. (Schuch, 1938) it has been shown that the eggs require a marked degree of moisture in their environment, and develop normally only when in direct contact with a moist substratum permitting access of air. If saturated air was the only source from which the eggs could absorb moisture, there was an increase in mortality and the newly hatched larvae were much shrivelled and notably lighter in weight than normal ones. On the other hand, eggs kept under water were gradually killed, presumably because of interference with their gaseous metabolism.

The cell constructed by the larva is its protective device: by its construction the larva is able to ensure a microclimate which is to a certain extent under its own control. There are certain conditions under which it is unable to form a cell—if the ground is too hard, or so saturated that the hole becomes filled with water—in which case the larva usually succumbs after a number of days. Fidler (1936) deals with the physical factors of the soil microclimate, and the relation between these and the behaviour of the larvae inhabiting it. The larvae used were those of the species *Serica brunnea*. The most important factors are shown to be soil temperature and soil moisture. He showed that there is a distinct relation between the water-content of the soil and the concentration of the body fluid of the larva. In the larval cell the larva can raise the humidity a small amount per cent. by evaporation, without dangerous loss of body fluid. In winter the temperature near the surface of the soil may reach a point below that which the insect can tolerate. The larva is able to evade this by migration downwards, where it is subjected to lack of oxygen and food, both retarding metabolism. He showed, however, that they can exist under practically anaerobic conditions at low temperatures. For *Melolontha melolontha* (Schwerdtfeger, 1939*a*) it has been shown that the larvae in the early instars became inactive at about 43°F. This relatively high point of inactivity would prevent larvae in position in the ground for hibernation from moving to a greater depth to escape increasing cold. This appears to be the reason for their normally hibernating at a depth of 19–24 inches, at which the lethal temperature is hardly ever reached. On the other hand, larvae of *Serica brunnea*, if stimulated by adverse conditions, are capable of movement to the optimum level even if the temperature is only a few degrees above their fatal zone (Fidler, 1936).

In autumn the limiting factor seems to be excess of soil moisture in the presence of relatively high temperatures: this is inclined to be fatal in itself, but is also favourable for a biotic factor in the larval ecology—development of fungoid and bacterial diseases. In summer larvae may suffer from lack of moisture. This also has the indirect effect of removing the food supply of the larva at a time when high temperatures have induced rapid metabolism (Fidler, 1936). Larvae of *Melolontha melolontha* are very resistant to variations in soil moisture, but if the absolute water content of the upper soil fall below 3% they move downwards, possibly because of the difficulty of moving in dry earth (Schwerdtfeger, 1939). Temperature changes at hibernation depths are much smaller than those at the surface; they decrease with increase in depth. The temperature of the surface soil is less affected by that of the air when there is a covering of vegetation. Larvae therefore would not undergo rapid fluctuations in temperature. There is a main temperature inversion in spring and autumn (Mail, 1930), when the deeper soil ceases to lose and gain heat respectively. McColloch and Hayes (1923) showed that whenever this change took place the larvae moved either up or down. Sweetman (1931) considers that the length of the life cycle is dependent upon the physical ecological factors.

Smith deals with the chemical factors of the soil habitat (acidity and humus values), and white grub distribution in relation to these. The acidity of soils in the grub-infested areas is uniformly high. On the Atherton Tableland the northern and north-western boundaries have been fairly stable for some time. This may be due to change in soil type with change of pH values from acid to alkaline. In areas subject to heavy rainfall soils will tend to become more and more acid through leaching, and the areas liable to grub infestation will become greater. Smith takes a critical pH value as 5·5, below which possible infestation is inferred. Following on removal of bases by leaching, is deterioration of physical characters from good crumb structure to single grain structure. *Lepidiota laevis* is restricted to definitely alkaline areas. In some parts of the world definite correlations have been established between soil texture and grub-susceptibility.

Australian Economic Species.

The majority of the damage is caused by the root-feeding larvae (with the outstanding exception of the two species, *Metanastes vulgivagus* and *Heteronychus sanctae-helenae*, in which the boring habits of the adults are directly responsible for weakening or death of the plants); the adults as a rule feed on the foliage of native plants, but there may be localized and sporadic outbreaks, in which vines and orchard trees are damaged (e.g., *Diphucephala colaspidoides*). Larval Scarabaeidae infest a large variety of plants, ranging from grass lands, lawns and field crops, to strawberries, Eucalypts, and young nursery trees, maize, sugar-cane and vegetables. The actual economic status of the family in Australia is at present indefinitely known. Larvae infesting the Queensland cane-fields present a serious problem; heavy damage to pastures occurs in Queensland (on the Atherton Tableland, where pasture deterioration due to scarabs is a serious matter); in New South Wales on the Dorrigo and Southern Tablelands and in coastal districts, in South Australia and in Victoria. The only introduced pest species is *Heteronychus sanctae-helenae*: the rest of the species which have become pests are indigenous. In many cases the first outbreaks have been of comparatively recent occurrence. Clearing of native scrub and coarse grass not only removed the natural source of food, but replacement by fine cultivated grasses, cereal crops, etc., has often created conditions favourable for survival, with abundant food.

Literature Cited.

FIDLER, J. H., 1936.—An Investigation into the Relation Between Chafer Larvae and the Physical Factors of their Soil Habitat. *J. Anim. Ecology*, 5, 333-347.

FROGGATT, W. W., 1919.—The White Grub or Grass Root Beetle. *Agric. Gaz. N.S.W.*, 30, 505-508.

FOX, H., and LUDWIG, D., 1937.—Methods of Breeding and Rearing Scarabaeidae. *Culture Methods for Invertebrate Animals*, 468-473.

————, 1938.—Growth and Survival of Japanese Beetle Larvae Reared in Different Media. *Ann. Ent. Soc. Amer.*, 31, 445-456.

HAWLEY, I. M., 1934.—A Preliminary Report on the Horizontal Movement of Grubs of the Japanese Beetle. *J. Econ. Ent.*, 27, 503-505.

————, 1935.—Horizontal Movement of Larvae of the Japanese Beetle in Field Plots. *J. Econ. Ent.*, 38, 656.

HAYES, W. P., 1929.—Morphology, Taxonomy and Biology of Larval Scarabaeoidea. *Ill. Biol. Monogr.*, 12 (2), pp. 119.

ILLINGWORTH, J. F., and DODD, A. P., 1921.—Australian Sugar-cane Beetles and Their Allies. *Bur. Sug. Exp. Stat. Qd. Div. Ent.*, Bull., 16.

MCCARTHY, T., 1928.—The Wheat Root Grub (*Anodontonyx tetricus*). *Agric. Gaz. N.S.W.*, 39, 306-313.

MCCOLLOCH, J. W., and HAYES, W. P., 1923.—Soil Temperature and its Influence on White Grub Activity. *Ecology*, 4, 29-36.

MAIL, G. A., 1930.—Winter Soil Temperatures and Their Relation to Subterranean Insect Survival. *J. Agric. Res.*, 41, 571-592.

RITCHER, P. O., 1939.—Observation on White Grub Pupation. *J. Kans. Ent. Soc.*, 12, 64-69.

SCHUCH, K., 1938.—Ueber den Einfluss der Feuchtigkeit auf das Eistadium des Maikäfers (*Melolontha melolontha* L.). *Arb. physiol. angew. Ent. Berlin*, 5, 220-225.

SCHWERDTFEGER, F., 1939.—Biologische Grundlagen der Engerlingsbekämpfung. *Z. Forst-u. Jadgwesen*, 71, 169-186.

————, 1939*a*.—Ueber den Einfluss der Winterkälte auf den Maikäferengerling. *Z. Pflanzenkrankheiten*, 49, 95-106.

SMITH, J. H., 1936.—White Grub Damage to Pastures on the Atherton Tableland. *Qd. Agric. J.*, 46, 446-466.

SWAN, D. C., 1934.—A Scarab Beetle (*A. tasmaniae* Hope) Destructive to Pastures in the South-east of South Australia. *J. Dept. Agric. S. Aust.*, 37, 1149-1156.

SWEETMAN, H. L., 1931.—Preliminary Report on the Physical Ecology of Certain *Phyllophaga* (Scarabaeidae, Col.). *Ecology*, 12, 401-422.

APPENDIX.

1. LITERATURE ON OVERSEAS WORK.

(*a*). *Miscellaneous.*

FLEMING, W. E., and BAKER, F. E., 1936.—A Method for Estimating Populations of Larvae of the Japanese Beetle in the Field. *J. Agric. Res.*, 53, 319-331.

————, and METZGER, F. W., 1938.—Control of the Japanese Beetle and its Grub in Home Yards. *Circ. U.S. Dept. Agric.*, 401, pp. 14.

————, and OSBURN, M. R., 1932.—Control of Larvae of the Japanese and Asiatic Beetles in Lawns and Golf-courses. *Circ. U.S. Dept. Agric.*, 238, pp. 10.

FIDLER, J. H., 1936.—Some Notes on the Biology and Economics of Some British Chafers. *Ann. Appl. Biol.*, 23, 409-427.

FOX, H., 1939.—The Probable Future Distribution of the Japanese Beetle in the United States. *J. N.Y. Ent. Soc.*, 47, 105-123.

HADLEY, C. H., and HAWLEY, I. M., 1934.—General Information about the Japanese Beetle in the United States. *Circ. U.S. Dept. Agric.*, 332, pp. 22.

HALLOCK, H. C., 1935.—Movements of Larvae of the Oriental Beetle (*Anomala orientalis*) Through Soil. *J. N.Y. Ent. Soc.*, 43, 413-425.

————, and HAWLEY, I. M., 1932 (revised 1936).—Life History and Control of the Asiatic Garden Beetle. *Circ. U.S. Dept. Agric.*, 246.

LUDWIG, D., and ABERCROMBIE, W. F., 1936.—Histological Changes Accompanying the Growth of the Mid-intestine of Japanese Beetle Larvae (*Popillia japonica* Newman). *J. Morph.*, 59, 113-122.

LUGINBILL, P., 1938.—Control of Common White Grubs in Cereal and Forage Crops. *U.S. Dept. Agric. Fmrs'. Bull.*, 1798, pp. 19.

PHILLIPS, W. J., and FOX, H., 1917 (revised 1933).—The Rough-headed Corn Stalk Beetle in the Southern States, and its Control. *U.S. Dept. Agric. Fmrs'. Bull.*, 875, pp. 6.

REX, E. G., 1934.—Information on the Japanese Beetle (a Survey of Data on *Popillia japonica* Newman in U.S.A.). *Circ. N.J. Dept. Agric.*, 242, pp. 34.

SMITH, L. B., and HADLEY, C. H., 1926.—The Japanese Beetle. *Circ. U.S. Dept. Agric.*, 363.

(*b*). *Physiology.*

LUDWIG, D., 1928.—The Development of Cold Hardiness in the Larva of the Japanese Beetle (*Popillia japonica* Newman). *Ecology*, 9, 303-306.

————, 1928.—The Effects of Temperature on the Development of an Insect (*Popillia japonica* Newman). *Physiol. Zool.*, 1, 358-398.

————, 1930.—The Effect of Exposure to Cold on the Embryonic Development of the Japanese Beetle (*Popillia japonica* Newman). *Physiol. Zool.*, 3, 291-299.

————, 1931.—The Effect of Temperature on the Growth Curves of the Japanese Beetle (*Popillia japonica* Newman). *Anat. Rec.*, 51, suppl., p. 44.

————, 1931.—Studies on the Metamorphosis of the Japanese Beetle (*Popillia japonica* Newman). i. Weight and Metabolism Changes. *J. Exp. Zool.*, 60, 309-323.

————, 1932.—Changes in the Glucose Content of the Japanese Beetle (*Popillia japonica* Newman) during Metamorphosis. *Anat. Rec.*, 54, suppl., p. 43.

————, 1932.—The Effect of Temperature on the Growth Curves of the Japanese Beetle (*Popillia japonica* Newman). *Physiol. Zool.*, 5, 431-447.

————, 1934.—Studies on the Metamorphosis of the Japanese Beetle (*Popillia japonica* Newman). ii. Changes in the pH of the Blood. *Ann. Ent. Soc. Amer.*, 27, 429-434.

————, 1934.—The Progression Factor in the Growth of the Japanese Beetle (*Popillia japonica* Newman). *Ent. News. Philad.*, 45, 141-153.

————, 1934.—Desiccation and Survival of the Japanese Beetle (*Popillia japonica* Newman). *Anat. Rec.*, 60, suppl., p. 44.

————, 1936.—The Effect of Desiccation on Survival and Metamorphosis of the Japanese Beetle (*Popillia japonica* Newman). *Physiol. Zool.*, 9, 27-42.

MADLE, H., 1934.—Zur Kenntnis der Morphologie, Oekologie und Physiologie von *Aphodius rufipes* Linn. und einigen verwandten Arten. *Zool. Jahr.* (*Abteilung für Anatomie und Ontogenie der Tiere*), 58, 303-396.

SCHUCH, K., 1938.—Laboratoriumsuntersuchungen uber den Lebensablauf des Maikäfers (*Melolontha melolontha* L.). *Arb. physiol. und angew. Ent.*, 5, 166-177.

SWINGLE, M. C., 1930.—Anatomy and Physiology of the Digestive Tract of the Japanese Beetle (*Popillia japonica* Newman). *J. Agric. Res.*, 41, 181-196.

(c). *Morphology.*

Boving, A. G., and Craighead, F. C., 1931.—An Illustrated Synopsis of the Principal Larval Forms of the Order Coleoptera, p. 51, Scarabaeoidea, key to families and subfamilies. *Ent. Amer. Brooklyn*, 11, pp. 351.

Fidler, J. H., 1936.—Some Notes on the Morphology of the Immature Stages of Some British Chafer Beetles. *Ann. Appl. Biol.*, 23, 114-132.

Jepson, W. F., 1937.—Observations on the Morphology and Bionomics of *Serica brunnea* L., with Notes on Allied Pests. Part 1. The Morphology of the Larva of *Serica brunnea* L. *Bull. Ent. Res.*, 28, 148-165.

Madle, H., 1934.—Zur Kenntnis der Morphologie, Oekologie und Physiologie von *Aphodius rufipes* L. und einigen verwandten Arten. *Zool. Jahr.* (*Abteilung für Anatomie und Ontogenie der Tiere*), 58, 303-396.

————, 1935.—Die Larven der Gattung *Aphodius*. *Arb. physiol. angew. Ent. Berlin*, 2, 298-304.

Sim, R. J., 1934.—Characters Useful in Distinguishing Larvae of *Popillia japonica* Newman and Other Introduced Scarabaeidae from Native Species. *Circ. U.S. Dept. Agric.*, 334, pp. 20.

Subklew, W., 1937.—Zur Kenntnis der Larven der Melolonthinae. *Z. Pflanzenkrankheiten*, 47, 18-34.

————, 1938.—Zur Morphologie der Larven von *Melolontha hippocastani*. *Arch. Naturgesch.* (N.F.), 7, 270-304.

Viado, G. B., 1939.—The External Anatomy and Diagnostic Characters of Some Common Philippine White Grubs. *Philipp. Agric.*, 28, 339-410.

Wade, J. S., 1934.—A Contribution to a Bibliography of the Described Immature Stages of North American Coleoptera. E. 358, *U.S. Dept. Agric. Bur. Ent.*, pp. 114, mimeogr.

(d). *Ecology.*

Fluke, C. L., Graber, L. F., and Koch, K., 1932.—Populations of White Grubs in Pastures with Relation to the Environment. *Ecology*, 13, 43-50.

Fox, H., 1935.—Some Misconceptions Regarding the Effects of the Cold of February, 1934, on the Larvae of the Japanese Beetle. *J. Econ. Ent.*, 28, 154-159.

————, 1937.—Seasonal Trends in the Relative Abundance of Japanese Beetle Population in the Soil during the Annual Life-cycle. *J. N.Y. Ent. Soc.*, 45, 115-126.

Graber, L. F., Fluke, C. L., and Dexter, S. T., 1931.—Insect Injury of Blue Grass in Relation to the Environment (*Phyllophaga* species). *Ecology*, 12, 547-566.

Madle, H., 1934.—Zur Kenntnis der Morphologie, Oekologie und Physiologie von *Aphodius rufipes* L. und einigen verwandten Arten. *Zool. Jahr.* (*Abteilung für Anatomie und Ontogenie der Tiere*), 58, 303-396.

(e). *Breeding and Rearing Technique.*

Baerg, W. J., and Palm, C. E., 1932.—Rearing the Rough-headed Corn Stalk Beetle. *J. Econ. Ent.*, 25, 207-212.

Fox, H., and Ludwig, D., 1937.—Methods of Breeding and Rearing Scarabaeidae. *Culture Methods for Invertebrate Animals*, 468-473.

Hayes, W. P., 1929.—Morphology, Taxonomy and Biology of Larval Scarabaeoidea. *Ill. Biol. Monogr.*, 12, pp. 119.

Peterson, A., 1937.—*A Manual of Entomological Equipment and Methods.* Part ii, pp. 334.

2. LITERATURE ON AUSTRALIAN ECONOMIC SPECIES.*

a. Sugar-cane. *Queensland.*

Fully 50 species of Scarabaeidae have been recorded from cane-fields. Of these the following are accounted major pests:

Lepidoderma albohirtum Waterh., *Pseudoholophylla furfuracea* Burm., *Lepidiota frenchi* Blkb., *Lepidiota trichosterna* Lea, *Lepidiota caudata* Blkb., *Anoplognathus boisduvali* Boisd., *Dasygnathus australis-dejeani* Macl.

Slightly injurious species are:

Anomala australasiae Blkb., *Isodon puncticollis* Macl., *Cacachroa decorticata* Macl., *Lepidiota consobrina* Gir., *Lepidiota grata* Blkb., *Lepidiota rothei* Blkb.

The information published on sugar-cane pest species is to be found in the *Queensland Agricultural Journal* (frequently under the heading "Cane Pest Combat and Control"), and in the Reports and Bulletins of the Division of Entomology of the Queensland Bureau of Sugar Experiment Stations.

b. Maize and Sugar-cane. *Queensland and New South Wales.*

Metanastes vulgivagus Olliff (*Pentodon australis* Blkb.). *Qd. Agric. J.*, 1924-1930—on sugar-cane.

Gurney, W. B., 1918.—Insect Pests of Maize. *Dept. Agric. N.S.W., Fmrs'. Bull.*, 116, 37-42.

————, 1934.—Records of Some New Insect Pests. *Agric. Gaz. N.S.W.*, 45, 452.

Cumpston, D. Margaret, 1940.—On the External Morphology, etc. Proc. Linn. Soc. N.S.W., lxv, 289-300.

* This literature has been grouped under the plants attacked and also under the specific insect concerned. Papers are not listed alphabetically, but according to the year of publication.

Lepidoderma albo-hirtum Waterh.
Attacking maize on the Atherton Tableland.
Smith, J. H., 1938.—Report of the Entomological Section. *Rep. Dept. Agric. and Stock Qd.*, 1937-38, 29-32.

c. Maize, Sugar-cane, Vegetable Crops, Banana, Grass Areas. *New South Wales.*
Heteronychus sanctae-helenae Blanch. (*H. arator* Burm.). *Agric. Gaz. N.S.W.*, 1934, 1936-1939.
Cumpston, D. Margaret, 1940.—On the External Morphology, etc. PROC. LINN. SOC. N.S.W., lxv, 289-300.

d. Cereal Crops. *New South Wales and S. Australia.*
Anodontonyx noxius Arrow (*A. tetricus* Blkb.).
McCarthy, T., 1928.—White Curl Grubs of the Wheat Root Beetle. *Agric. Gaz. N.S.W.*, 39, 54.
————, 1928.—The Wheat Root Grub (*Anodontonyx tetricus*). *Agric. Gaz. N.S.W.*, 39, 306-313.
Davidson, J., 1930.—White Grubs. *J. Dept. Agric. S. Aust.*, 34, 224-227.
Arrow, G. J., 1932.—A Few New Species of *Melolonthine* Coleoptera. *Ann. and Mag. N. Hist.*, Ser. 10, ix, 189-197. (Concerning erroneous identification of *A. tetricus.*)

e. Strawberry, Grasses, Eucalypts, Orchard Trees. *New South Wales.*
Anoplognathus analis.
Froggatt, W. W., 1915.—Insect Pests of the Strawberry. *Agric. Gaz. N.S.W.*, 26, 133-137.
Anoplognathus chloropyrus.
Froggatt, W. W., 1920.—Three Native Beetles attacking Orchard Trees. *Agric. Gaz. N.S.W.*, 31, 421-426.

f. Pastures. *S. Australia, New South Wales, Victoria, Queensland.*
Aphodius tasmaniae Hope (*A. howitti* Hope, *A. andersoni* Blkb.).
Swan, D. C., 1934.—A Scarab Beetle (*A. tasmaniae* Hope) destructive to Pastures in the S.E. of South Australia. *J. Dept. Agric. S. Aust.*, 37, 1149-1156.
Insect Pests and Their Control. 1937. *Aphodius howitti. Agric. Gaz. N.S.W.*, 48, 617-618.
Pescott, R. T. M., 1937.—Insect Pests of Subterranean Clover. *J. Dept. Agric. Vict.*, 35, 371-375.
Entomological Investigations, 1931-32.—*6th A.R. Counc. Sci. Indust. Res. Aust.*, 20-23.
Lepidiota caudata Blkb.
Atherton, D. O., 1931.—Grass Pests of the Atherton Tableland. *Qd. Agric. J.*, 36, 474-481.
Pseudoholophylla furfuracea Burm., *Lepidiota caudata* Blkb., *Rhopea* spp., *Lepidiota laevis.*
Smith, J. H., 1936.—White Grub Damage to Pastures on the Atherton Tableland. *Qd. Agric. J.*, 46, 446-466.
————, 1936.—White Grub Injury to Pastures elsewhere in Queensland. *Ibid.*, p. 467.
————, 1939.—White Grubs and Pasture Deterioration on the Atherton Tableland. *Qd. Agric. J.*, 52, 484-522.

g. Lucerne, Strawberry, Pastures, Cereal Crops, Sugar-cane. *Victoria, S. Australia, Queensland.*
Heteronyx species.
French, C., 1915.—An Insect Pest of Lucerne: Cockchafer Grubs. (*Heteronyx piceus* Blanch.). *J. Dept. Agric. Vict.*, 13, 567-569.
Dodd, A. P., 1917.—The Cane Grubs of Australia. Part ii. *Bur. Sug. Exp. Stat. Qd. Div. Ent.*, Bull., 6, pp. 30.
Davidson, J., 1930.—White Grubs. *J. Dept. Agric. S. Aust.*, 34, 224-227.
Adam, D. B., and Pescott, R. T. M., 1932.—Strawberry Culture. Fungus Diseases and Insect Pests. *J. Dept. Agric. Vict.*, 30, 21-25. (Also *Haplonyx* species.)

h. Pastures, Cereal Crops, Strawberry; Adults on Acacias, Vines, Orchard Trees. *Victoria, S. Australia.*
Diphucephala colaspidoides Gyll.
Davidson, J., 1930.—White Grubs. *J. Dept. Agric. S. Aust.*, 34, 224-227.
————, 1931.—Insects Observed on Crops in S. Australia during Period June, 1928-June, 1930. *Ibid.*, 741-745.
————, 1932.—Insects Observed on Crops in S. Australia during Period June, 1930-June, 1932. *Ibid.*, 36, 283-286.
————, 1935.—Insects Observed in Crops in S. Australia during Period June, 1932-June, 1934. *Ibid.*, 38, 998-1003.
French, C., 1933.—New Records of Plants attacked by Native Insects. *Vict. Nat.*, 50, p. 47, p. 56.
Pescott, R. T. M., 1934.—Insect Pests of the Cherry. *J. Dept. Agric. Vict.*, 32, 93-94.

i. Grasses, Sugar-cane. *Queensland, New South Wales.*
Sericesthis pruinosa Dalm. (*Scitala pruinosa* Dalm.).
Froggatt, W. W., 1919.—The White Grub or Grass Root Beetle. *Agric. Gaz. N.S.W.*, 30, 505-508.
Mungomery, R. W., 1928.—Rep. Asst. Ent. at Bundaberg, *28th Rep. Bur. Sug. Exp. Stat. Qd.*, 23-26.